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Research and Development of Region Power Grid Wind Hazard Precaution System

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Abstract

The severe wind is one of the most threatening natural disasters for power grid operation. To solve the problem of the wind hazard assessment of power grid, a region power grid wind hazard precaution system is proposed in this paper by using weather and power grid data and geographical information. This system consists of two forecast models that the first is the statistical diagnosis model based on Partial least-squares and Model Output Statistics (PLS-MOS) method, and the second is the numerical forecasting model by the combination of mesoscale numerical model and microscale boundary layer model (MM5-CALMAT). Finally, according to the wind-resistant design parameters of transmission towers, a precaution information management platform based on the grid disaster prevention and reduction system (GDPRS) is supplied in order to remind the relevant operator for their decision-making and emergency treatment through real-time SMS and GIS location display. It is of important practical significance and application value for power grid disaster prevention and reduction.

*Keywords:*wind hazard precaution; region power grid; statistical diagnosis model; numerical forecasting model; GDPRS

1. Introduction

According to failure statistics, the transmission line trip caused by natural environmental factors is about 70% of the total trips, then most power grid accident adapted from natural disasters [1]. The severe wind is one of the most threatening natural disasters for power grid operation. The severe wind such as typhoon, downburst, and tornado can lead to flashover, lightning trip, etc., and will cause collapse of transmission towers in severe case [2]. Currently, related research focuses on the wind-resistant design

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through theoretical analysis [3] and wind tunnel investigation [4] on dynamic behavior and wind-induced response of transmission line system, that in order to enhance the wind resistance of transmission lines by improving the wind resistant design for transmission towers. Considering the actual operation state of power grid, the severe storm on extreme weather conditions in the special terrain can easily exceed the wind-resistant design security standards of towers. At this point it would be unwise to blindly raise design standards, then should be combined with risk assessment of wind hazard for transmission lines and further study the essence of the occurrence and development of the severe storm produced. Though forecasting extreme wind distribution and early warning by classification on the affected transmission towers, it is in order to remind the relevant operator for their decision-making and emergency treatment.

This paper presents the severe wind statistical diagnosis model and the numerical forecasting model, based on combination between the theoretical modeling and numerical simulation, and realizes the forecast extreme wind distribution on the complex terrain conditions. Moreover, through combined with wind-resistant design parameters to establish tower damaged probability model, the prediction and precaution on power grid wind hazard is realized on the platform of GDPRS.

2. Model Description

2.1 The Statistical Diagnosis Model

The core algorithm of this model is Partial least-squares (PLS) regression. PLS regression is a novel multivariate data analysis method developed from the practical applications [5]. During the last two decades, PLS regression has developed rapidly in both theory and applications. PLS regression is mainly used for regression modeling between multi-dependent variables and multi-independent variables. Moreover, comparing with ordinary multiple regression, PLS regression possesses many advantages, such as avoiding the harmful effects of multicollinearity, and being capable of building the models when the number of observations is less than the number of variables, etc. In addition, PLS regression effectively integrates the basic functions of regression model, principal components analysis (PCA) and canonical correlation analysis.

At first, the predictors X and the predictand Y are normalized

$$E_0=(E_{01}, E_{02}, \ldots E_{0p})_{n\times p},\ F_0=(F_{01}, F_{02}, \ldots F_{0q})_{n\times q}$$

Let be t_1 and u_1 are respectively the first component of E_0 and F_0, then $t_1=E_0w_1$, $\|w_1\|=1$and $u_1=F_0c_1$, $\|c_1\|=1$.

According to principal components analysis, there should be met $Var(t_1)\to\max$, $Var(u_1)\to\max$.

Meanwhile, the regression modeling requests the greatest interpreting ability of t_1 to u_1, that is $r(t_1, u_1)\to\max$.

Thus this mathematical problem can be expressed as

$$\max(E_0w_1, F_0c_1) \quad s.t.\colon \|w_1\|=1, \|c_1\|=1 \tag{1}$$

And using Lagrangian algorithm gives,

$$s=w_1^TE_0^TF_0c_1- \lambda_1(w_1^T w_1-1)- \lambda_2(c_1^T c_1-1) \tag{2}$$

Solving Eq. (2) gives $2\lambda_1=2\lambda_2=w_1^TE_0^TF_0c_1$.

Let be $\theta_1=2\lambda_1=2\lambda_2$, then $E_0^TF_0F_0^TE_0w_1=\theta_1^2w_1$.

where w_1 and θ_1^2 are respectively the eigenvector and eigenvalue of $E_0^TF_0F_0^TE_0$.

Then solves the three regression equations of E_0 and F_0 to t_1 and u_1 respectively,

$$E_0 = t_1p_1^T + E_1,\ p_1 = \frac{E_0^T t_1}{\| t_1 \|^2} \tag{3}$$

$$F_0 = u_1 q_1^T + F_1^*,\ q_1 = \frac{F_0^T u_1}{\| u_1 \|^2} \tag{4}$$

$$F_0 = t_1 r_1^T + F_1,\ r_1 = \frac{F_0^T t_1}{\| t_1 \|^2} \tag{5}$$

After getting E_1 and F_1, the above processes are not repeated until met the condition of cross validation test, and get the regression equation,

$$F_0 = t_1 r_1^T + t_2 r_2^T + \ldots + t_A r_A^T + F_A \tag{6}$$

Introducing $E_h = E_0 \prod_{j=1}^{h} (I - w_j p_j^T)$, where $t_h = E_0 w_h^*$ and $w_h^* = \prod_{j=1}^{h-2} (I - w_j p_j^T) w_h$, thus Eq. (6) can be rewritten as

$$\begin{aligned} F_0 &= E_0 w_1^* r_1^T + E_0 w_2^* r_2^T + \ldots + E_0 w_A^* r_A^T + F_A \\ &= E_0 (\sum_{j=1}^{A} w_j^* r_j^T) + F_A \end{aligned} \tag{7}$$

Let be $B = \sum_{j=1}^{A} w_j^* r_j^T$, then

$$F_0 = E_0 B + F_A \tag{8}$$

This model selects the number of components using cross validation test, and considers that increase the h component is beneficial when

$$\frac{S_{PRESS,h}}{S_{ss,h-1}} \le 0.95^2 \tag{9}$$

where $S_{ss,h\text{-}1}$ is the equation fitting error which has h-1 components using all sample points, $S_{PRESS,h}$ is the disturbance error which has h components but rejects the selected sample point.

The calculation process of this model is shown in Fig. 1. The calculated results include true value, forecast value, error value, average relative error, forecast variances and correlation.

Therein, the sample space is built by the combination of vertical cumulative and lateral sliding method. Therein vertical cumulative method makes the sample space which is combined predictor of the forecasting same days of all previous years. The lateral sliding method carries out forwarding the forecasting day, according to the own needs and the results good or bad adjusted the number of forwarding days. Therefore the vertical cumulative - lateral sliding method forms a new sample space for the PLS regression modeling by combined the above two sample spaces together. Finally, the statistical forecast on wind speed of each weather site will be realized by combined the Model Output Statistics (MOS) forecasting technique.

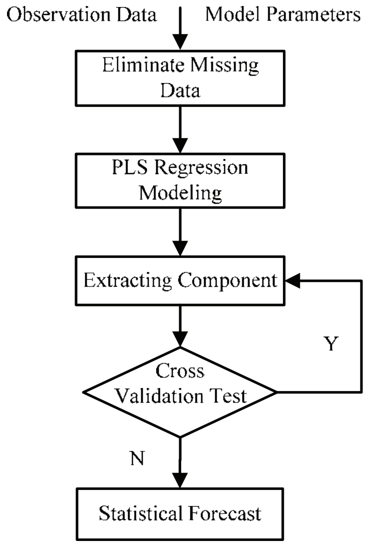

Figure 1. Calculation process of statistical model

2.2 The Numerical Forecasting Model

The basic idea of assessment and prediction of the severe wind model is: firstly, through dynamical downscaling method, the initial and boundary conditions provided by the global numerical model and reanalysis data are used to driven the severe wind assessment and forecast system coupled by meso-micro scale meteorological numerical model. Then the wind field of 1-3km resolution mesoscale and 100-200m resolution microscale will be provided in simulation results. Secondly, tracking monitoring, forecasting and assessment on the wind resources can be realized by statistical downscaling analyzed on simulation results.

The structure of this model is shown in Fig. 2. Input layer include all input conditions that numerical model calculation needed such as: ground and upper-air observation, radar data, large-scale climatology, mesoscale and local orography, local observation, land use, etc.

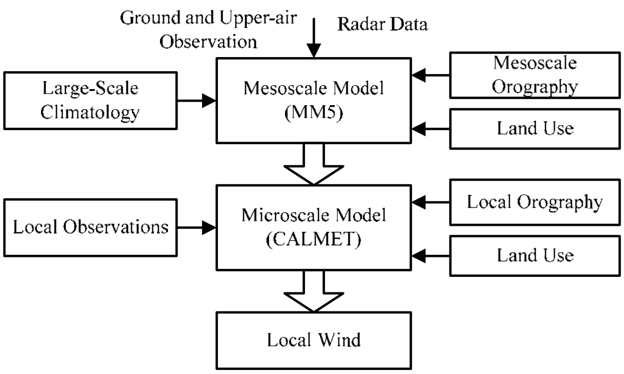

Figure 2. Structure graph of numerical model

In this model, the diagnostic wind field module consists of two steps: first of all, the MM5 model output wind field act as the first interpolation field and input the CALMET model [6-7]. Namely the MM5 forecast results of resolution 1km are interpolated to the CALMET diagnostic model of resolution 100m×100m grids, through adjusted the effects of kinetics of the terrain, tilt airflow and blocking, etc. Secondly, the high-resolution, multi-layer surface wind field is obtained by objective analyzed on observation data including ground and upper-air observation and radar data. Though further statistical downscaling analyzed on simulation results by using the statistical model of PLS-MOS, the quantitative assessment and prediction on variation of wind speed can be achieved.

3. System Establishment

This precaution system built on the grid disaster prevention and reduction system (GDPRS) platform. The sketch of overall architecture is shown in Fig.3.

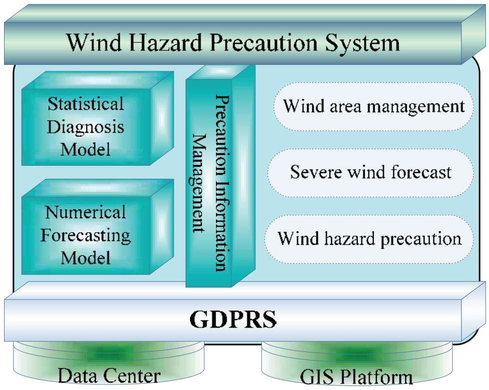

Figure 3. Sketch of overall architecture

GDPRS intensively integrated various power professional systems based on power data center and GIS platform, and also concentrated much external information which is related to power system, such as meteorology, geology, water, fire, etc. It implements a variety of applications that power grid status query, environmental monitoring, disaster forecasting, emergency repair, thematic analysis, decision and command, etc., in order to provide a visualization decision-oriented management platform for grid disaster prevention and reduction and emergency command.

Each transmission tower has its rated design wind speed, and set as V. The tower actual ability to withstand wind loads is higher than the design standards, but there were no reports related research on the much "higher". In addition, the steel ultimate loads often have properties of the exponential growth in large deformation. This paper supposes the tower damaged probability $\lambda(v)$=0 when forecast wind speed v less than design wind speed V, and $\lambda(v)$=1 when v>2V, and then $\lambda(v)$ is the exponential growth function of v when V<v<2V. So a tower damaged probability model based on forecast wind speed can be obtained,

$$\lambda(v) = \begin{cases} 0 & ,v \le V \\ \exp\left[\dfrac{\ln 2(v-V)}{V}\right] - 1 & ,V < v < 2V \\ 1 & ,v \ge 2V \end{cases} \tag{6}$$

The calculated tower damaged probability is corresponding to the four precaution levels, defined as follows,

(1) Red level, when $\lambda(v)$≥80%;
(2) Orange level, when 50%≤$\lambda(v)$<80%;
(3) Yellow level, when 20%≤$\lambda(v)$<50%;
(4) Green level, when 0≤$\lambda(v)$<20%.

4. Functional Implementation

This precaution system mainly consists of three modules: wind area management module, severe wind forecast module, and wind hazard precaution module.

Therein, the wind area management module includes historical wind area map display, real-time wind distribution, and wind hazard grade distribution map. Based on each weather site statistical data, the above average, maximum and extreme wind speed distribution maps are obtained, through chromatism filled with contour interpolation algorithm and choroplethic map (see Fig.4).

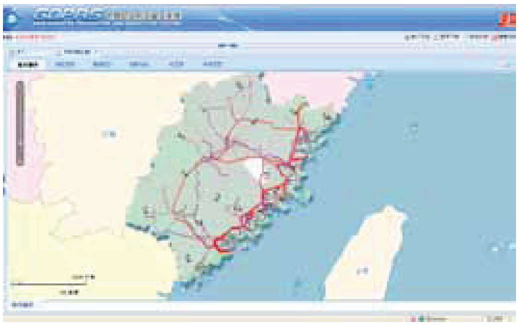

Figure 4. The interface of real-time wind area map

The severe wind forecast module includes the forecasting of the statistical model and the numerical model, and typhoon prediction and precaution. The forecast results of the above two models are hourly shown on 24h and 72h forecast period respectively. The forecast track, intensity and wind field distribution of typhoon are real-time displayed by 3D animation. This system presents the return analysis in order to test the model prediction accuracy, then the comparison result of forecast and observation is shown that forecast effect is relative ideal (see Fig. 5).

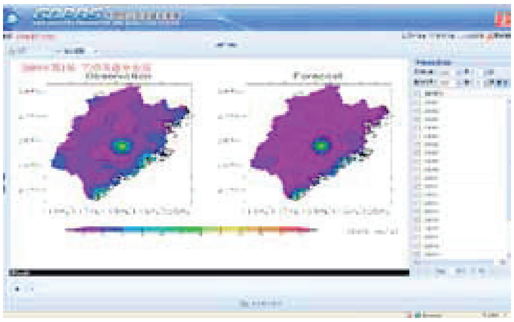

Figure 5. The comparison result of forecast and observation

The wind hazard precaution module includes wind hazard grade precaution and short message alarm. The precaution information on danger transmission line and its towers can be obtained by using tower damaged probability model. It is very important to remind the relevant operator for their decision-making and emergency treatment through real-time SMS and GIS location display (see Fig.6).

Figure 6. The interface of wind hazard precaution module

Conclusions

Through widespread investigation on status quo of wind hazard prevention for power grid and countermeasures, combined the latest research progress on meso-micro scale meteorology and model diagnosis, this paper first introduced the severe wind statistical diagnosis model based on each weather site by using partial least squares regression method combined the model forecast method. Moreover, the typhoon numerical forecasting model on the complex terrain conditions by using mesoscale regional meteorological numerical model and microscale boundary layer numerical model combined statistical downscaling diagnostic techniques. Finally, according to the wind-resistant design parameters of transmission tower, a power grid wind hazard precaution system is realized on the platform of GDPRS.

This system can provide a theoretical basis and scientific guarantee for the wind-resistant safety and investment estimation of engineering design on the region power grid transmission system. Moreover, it can further perfect the hazard prediction and precaution system, and improve the forecast ability of the severe wind hazard. The research results will effectively ensure the wind-resistant safety of the transmission towers in study region, resulting in more economic benefits and demonstration effect. Furthermore, through real-time response on the operation risk condition of power grid, it will be extensive application prospects on wind hazard prevention and power system planning.

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